Landfill Siting Using GIS and AHP (Analytical Hierarchy Process): A Case Study Al-Qasim Qadhaa, Babylon, Iraq

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Abstract: The selection of a landfill site is considered as a complicated task because this process is based on many factors and restrictions. For Al-Qasim Qadhaa, which is situated in the southern part of the Babylon Governorate, Iraq, there is no landfill site in that area that conforms to the scientific criteria for selecting sites for landfill. For this reason, 15 criteria were adopted in this study (groundwater depth, rivers, soil types, agriculture lands use, land use, elevation, slope, gas pipelines, oil pipelines, power lines, roads, railways, urban centers, villages and archaeological sites) using GIS (geographic information system), which has a large ability to manage input data. In addition, the AHP (analytical hierarchy process) method was used to derive the relative weightings for each criterion using pair-wise comparison. To obtain the suitability index for candidate landfill sites, a weighted linear combination method was used. After combining these methods, two suitable candidate landfill sites, with areas of 2.766 km² and 2.055 km², respectively, were found to satisfy the scientific and environmental requirements. The area of these sites can accommodate solid waste from 2020 until 2030 based on the required area, which was 0.702 km².

Key words: Landfill, Al-Qasim Qadhaa, AHP (analytical hierarchy process), GIS, WLC (weighted linear combination).

1. Introduction

In developing countries, solid waste management is considered one of the important issues related to environmental management and, through proper management of solid waste, pollution and the health risks which arise in open dumping sites that are often commonly used for the disposal of this waste can be avoided [1]. MSW (management of solid waste) consists of many processes, including recycling, reducing the waste, recovery of energy, incineration of the waste, and landfill [2]. A sanitary landfill is necessary to a waste management system even if other techniques of waste management are adopted. In countries that burn or recycle large parts of their waste, the remains of these processes still need a suitable landfill site because landfill is simple to use and relatively cheap [3-5]. Within the last two decades, researchers have exerted great efforts in satisfying

different aspects of landfill management, particularly selecting a suitable site for landfill [6, 7]. The process of site selection is considered to be one of the most difficult tasks related to solid waste management systems and a major concern for planners and authorities. This is because this process is subject to factors such as government regulation, government and municipal funding, urbanization, increasing population densities, growing environmental awareness, public environmental health, reduced land availability for landfills and increasing political and social opposition to the establishment of landfill sites [8, 9].

GIS (geographic information system) and a spatial multi-criteria decision analysis should be used in landfill siting because they are powerful, integrated tools used to solve the problem of landfill site selection. Decision makers often use MCDA (multi criteria decision analysis) to handle large quantities of complex information. GIS has a significant role in contributing to the selection a landfill site. There are many advantages of applying GIS in the process of landfill

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siting. It reduces time and cost in the siting process, and it has a high ability to manage large volumes of spatial data from variety of sources. GIS may also be used for identifying routes for transporting waste to transfer stations and then to a landfill site and vice versa [2, 10 11]. AHP (analytical hierarchy process) is a multi-criteria decision-making approach that was developed by Saaty [12] in 1980 to standardize these multi-criteria in the process of making decisions. The mathematical properties of AHP have attracted the attention of many researchers because the required input data are easy to obtain. This process can be used to solve complex multi-criteria decision-making problems. It uses a multi-level hierarchical structure to determine the weighted percent of the multi-criteria [13]. AHP is used to determine the most suitable landfill site among many candidate sites. The relevant data are utilized to obtain relative weightings using pair-wise comparisons of decision criteria in a matrix of the problem [2, 14, 15].

In the literature [7, 16-18], several potential landfill sites have been identified among many candidate sites using GIS and AHP.

This study seeks to identify a suitable candidate site

for landfill through using the AHP, weighted linear combination method and GIS in Al-Qasim Qadhaa in the Babylon Governorate, Iraq.

2. Methodology

2.1 Study Area

Al-Qasim Qadhaa is considered one of the major cities of the newly formed Babylon Governorate, Iraq. Until recently, the cities of this Qadhaa (Al-Qasim and Al-Talyaah) were administratively controlled by Al-Hashimiyah Qadhaa, which is located in the southern part of the Babylon Governorate, between Al-Hillah Qadhaa and Al-Hashimiyah Qadhaa (Fig. 1).

Al-Qasim Qadhaa has an area of 637 km², which constitutes 17.1% of the total area of the Babylon Governorate [19]. It is situated between longitude 44°27'41" E and 44°49'24" E, and latitude 32°25'53" N and 32°5'53" N (Fig. 1).

The official population of Al-Qasim Qadhaa was 184,605 inhabitants in 2015 [20], which equates to 8.8% of the total population of the Babylon Governorate. Around 146,465 (79.33%) of the inhabitants live in urban regions, and 38,139 (20.67%) of the inhabitants live in rural regions.

Fig. 1 The study area across Al-Qasim Qadhaa, Babylon Governorate, Iraq.

2.2 Decision-Making Tree for Landfill Siting

The selection of a suitable landfill site considers the main aim of the decision hierarchy. The hierarchical structure of the decision problem includes three levels. The first level has been classified into two categories: natural environmental factors and artificial factors. The second level is comprised of six categories of the criteria: hydrological, land, topographical, infrastructure, accessibility and social-cultural. The third level included 15 criteria used to establish suitable candidate sites for landfill in this study. These criteria are groundwater depth, rivers, soil types, agriculture lands use, land use, elevation, slope, gas pipelines, oil pipelines, power lines, roads, railways, urban centers, villages and archaeological sites (Fig. 2).

2.3 Preparing Layers Maps of Criteria

After selecting the important criteria that are related to the present study, the required maps were obtained to prepare the digitized criteria map layers. Some of these maps were digital as a shape file (vector), while the remaining maps need to be converted to be digital maps as a shape file. The individual shape file maps for topography, slope, river, road, urban centers, villages, gas pipelines, oil pipelines, power lines and railways were prepared accordingly using the internal reports of

the Iraqi Ministry of Education. The readings of 170 wells for the depths of groundwater were entered into GIS to generate an interpolation between them using the spatial extension tool called Kriging in order to produce the shape file of groundwater depths [21]. For creating the shape file of “soil types”, the map of exploratory soil of Iraq (scale 1:1,000,000) [22] was used. The shape file of “agricultural land” was obtained using the land capability map of Iraq (scale 1:1,000,000) and was checked by analyzing satellite images of the Babylon Governorate from 2011 [23]. The archaeological map of Iraq (2013) [24] indicates the locations of archeological and religious sites in this Qadhaa. The map of industrial areas (scale 1:400,000) [19] shows industrial areas within this Qadhaa. These maps were prepared within GIS using its spatial analysis tools as a separate shape file using the relevant information in each map, and then they were converted to the raster maps. All information was projected onto WGS (world geodetic system) 1984 using a projected coordinate system [25].

2.4 Restriction of Locations Using Buffer Zone

Identifying the most suitable site for landfill needs a process of large-scale evaluation. Any chosen site should satisfy the governmental regulations requirements

Fig. 2 Tree diagram of the decision process developed for selection of suitable landfill site.

as well reducing environmental, economic and social costs [14]. Restricted sites mean areas which do not allow for a landfill site to be situated within them due to potential risk to the environment, human health or excessive cost [13]. Buffer zones, or spatial constraints, were used around important sites or specific geographic features in each criterion in the GIS environment using the special extension tool “buffer”. Table 1 shows the buffer zones of the criteria for unsuitable areas that were used in landfill siting in Al-Qasim Qadhaa.

2.5 Preparing Grading Values for Sub-criteria

In this study, based on the opinion of experts and literature reviews in this field, as well as various required and available data about the study area, each criterion was classified into classes (sub-criteria), and each class was given a suitability grading value. This was carried out by decision makers who gave their opinions about the sub-criteria. In order to prepare each criterion and sub-criteria, a number of steps were performed in GIS (e.g., buffer, clip, extract, overlay, proximity, convert, reclassify and map algebra, etc.) (Table 2).

2.5.1 Groundwater Depth

To prepare the groundwater depths layer for Al-Qasim Qadhaa, the Kriging tool in GIS was used to generate an interpolation between the available data of

groundwater depths in 170 wells throughout the Babylon Governorate [21]. These measurements were carried out from 2005 to 2013. Generally, the groundwater depths in the Babylon Governorate are shallow. These depths removed certain areas as appropriate for site selection for landfill because of a risk of contaminating the groundwater through leaching.

Various depths have been suggested as sufficient: Effat and Hegazy [27] suggested that a depth of 6 m from a site's surface to the groundwater table is a suitable depth, Delgado et al. [11] suggested 10 m, Ouma et al. [41] propose 15 m, and Sadek et al. [40] suggested 30 m.

In this study, depths of between 0~1.5 m, 1.5~3 m, 3~4.5 m and more than 4.5 m to groundwater were given a grading value of 1, 4, 6 and 10, respectively (Fig. 3a).

2.5.2 Rivers

In this study, a distance less than 1,000 m from the boundaries of a river was given a score value of 0 to reduce the potential for river contamination from landfill. Distances greater than 1,000 m were given a grading value of 10 (Fig. 3b).

2.5.3 Elevation

This study adopted the DEM (digital elevation model) [21, 22]. The raster elevation map was divided into three categories according to the study area. In this

Table 1 Description of buffer zones criteria values.

Criteria	Description	Researchers' suggested buffers
Groundwater depth	The zones of groundwater depth between 0~1.5 m should be avoided in selection sites for landfill	1.5 m [26]; 6 m [27]; 10 m [11]
Land use	Industrial area, university and agricultural lands should be excluded from land fillsiting	
Rivers	Sites should be at a distance of more than 1 km from rivers	1 km [7, 28]; 0.8 km [14]; 0.5 km [29]
Roads	Sites should be at a distance of more than 500 m from roads	1 km [28, 30]; 0.5 km [27, 31]
Railways	Sites should be at a distance of more than 500 m from railways	500 m [6, 32, 33]
Urban centers	Sites should be at a distance of more than 5 km from streams	5 km [27, 33, 34]; 3 km [35]
Villages	Sites should be at a distance of more than 1 km from borders of village	1 km [31,36]; 0.8 km [35]
Archaeological sites	Sites should be at a distance of more than 1 km around archaeological sites	0.5 km [7]; 1 km [13, 37]; 3 km [30]
Gas pipelines	Sites should be at a distance of more than 300 m from gas pipelines	250 m [33, 38]
Oil pipelines	Sites should be at a distance of more than 75 m from oil pipelines	250 m [38]
Power lines	Sites should be at a distance of more than 30 m from power lines	30 m [31, 39]; 40 m [40]; 50 m [29]

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Table 2 Summary of the input layers used in the analysis.

No.	Criteria	Sub-criteria values	Sub-criteria rating	Description scale	Criteria weights (AHP)
1	Groundwater depth (m)	0~1.5	1	Not suitable	0.2004
		1.5~3	4	Moderately suitable	
		3~4.5	6	Suitable	
		> 4.5	10	Most suitable	
2	Rivers (m)	0~1,000	0	Not suitable	0.1471
		> 1,000	10	Most suitable	
3	Elevation (a.m.s.l.)	15~22	3	Moderately suitable	0.0709
		22~29	7	Suitable	
		> 29	10	Most suitable	
4	Slope (degree)	0°~5°	10	Most suitable	0.0463
5	Soils types	Soil 6 (A)	10	Most suitable	0.0709
		Soil 5' (B)	9	Suitable	
		Soil 9 (C)	7	Moderately suitable	
		Soil 4 (D)	5	Less suitable	
6	Land use	Industrial area	0	Not suitable	0.0302
		Urban centers	0	Not suitable	
		Villages	0	Not suitable	
		University	0	Not suitable	
		Rivers	0	Not suitable	
		Archaeological sites	0	Not suitable	
		Agricultural lands	0	Not suitable	
		Orchards	5	Suitable	
		Unused lands	10	Most suitable	
7	Agricultural land use	Agricultural land	0	Not suitable	0.0462
		Orchards	5	Suitable	
		Unused land	10	Most suitable	
8	Roads (m)	0~500	0	Not suitable	0.0463
		500~1,000	7	Suitable	
		1,000~2,000	10	Most suitable	
		2,000~3,000	5	Moderately suitable	
		> 3,000	3	Less suitable	
9	Railways (m)	0~500	0	Not suitable	0.0107
		> 500	10	Most suitable	
10	Urban centers (m)	0~5,000	0	Not suitable	0.1471
		5,000~10,000	10	Most suitable	
		10,000~15,000	7	Suitable	
		> 15,000	4	Moderately suitable	
11	Villages (m)	0~1,000	0	Not suitable	0.1038
		> 1,000	10	Most suitable	
12	Archaeological sites (m)	0~1,000	0	Not suitable	0.0302
		1,000~3,000	5	Moderately suitable	
		> 3,000	10	Most suitable	
13	Gas pipelines (m)	≤ 300	0	Not suitable	0.0146
		> 300	10	Most suitable	
14	Oil pipelines (m)	≤ 75	0	Not suitable	0.0146
		> 75	10	Most suitable	
15	Power lines (m)	≤ 30	0	Not suitable	0.0207
		> 30	10	Most suitable	

Note: AHP: analytical hierarchy process; a.m.s.l.: above mean sea level.

Fig. 3 Suitability index maps of: (a) ground water depth; (b) rivers; (c) elevation; (d) slope; (e) soil types; (f) land use; (g) agricultural land use; (h) roads; (i) railways.

study, moderately suitable elevations were between 15~22 (a.m.s.l.) and between 22~29 (a.m.s.l.). Elevations of greater than 29 (a.m.s.l.) were the most suitable for a landfill. These categories were given grading values of 3, 7 and 10, respectively (Fig. 3c).

2.5.4 Slope

All lands of Al-Qasim Qadhaa have a slope less than 5° and so were given a rating value of 10 (Fig. 3d). These lands were considered the best for a landfill siting to prevent the transition of pollutants to surrounding areas. A suitable slope ranges between 0°~5° is necessary to prevent the transition of pollutants to surrounding areas [13, 33].

2.5.5 Soil Type

There are four types of soils in Qasim Qadhaa Buringh (1960) (Fig. 3e). These soil groups are: basin depression soils A (6), river basin soils, poorly drained B (5'), silted haur and marsh soils C (9) and river levee soils D (4). These types of soils were giving scores of 10, 9, 7 and 5, respectively. The short description of the characteristics for each type of soil can be found in Refs. [22, 42].

2.5.6 Land Use

A number of maps were incorporated to prepare the land use layer of the study area. All land classified into one of nine categories (features): urban centers, villages, industrial areas, archaeological sites, universities, rivers, agricultural land, orchards and unused land. The land use layer was created by importing shape files for all categories into a GIS environment in polygon type. The shape file of "urban" included all cities in Al-Qasim Qadhaa. The villages which spread within this Qadhaa were incorporated in the shape file of "villages". The "agricultural land" shape file was created by analyzing satellite images of the Babylon Governorate in 2011 and the land capability map of Iraq (scale 1:1,000,000). The shape file of the Green University of Al Qasim was mapped in polygon type from satellite images of the Babylon Governorate in 2011. The maps used had scales of 1:400,000 and 1:1,500,000 to determine the shape files

for industrial areas and archaeological sites, respectively. The shape file of "Al-Qasim Qadhaa rivers" was a clipping from the shape file of "Babylon Governorate rivers". All shape files were merged into a single layer called "land use". The categories of "orchards" and "unused lands" were given ratings of 5 and 10, respectively, while other categories were assigned a score of 0 (Fig. 3f).

2.5.7 Agricultural Land Use

The lands for Al-Qasim Qadhaa were divided into three categories: agricultural land, orchards and unused lands. The categories of orchards and unused lands were drawn in polygon type in separate shape files based on analyzed satellite images of the Babylon Governorate in 2011 [23] and the land capability map of Iraq (scale 1:1,000,000) [43]. In order to prepare the features of "agricultural land", the features of "orchards" and "unused land" were merged into one feature. Then, the special extension tool "erase" in GIS was used to extract the areas of agricultural land. These features were then merged into a single shape file and then converted to a raster map called "agricultural land use" (Fig. 3g). The categories of "unused land", "orchards" and "agricultural land" were given a grade of 10, 5, and 0, respectively, according to the classification of the Iraqi Ministry of Agriculture.

2.5.8 Roads

In this study, main roads and highways were incorporated into the layer of "roads". Buffer zones from roads to landfill sites of 1,000~2,000 m were assigned the highest score of 10. Buffer zones of less than 500 m, and those greater than 3,000 m, were given a grading of 0 and 3, respectively. Buffer zones of 500~1,000 m were assigned a grade of 7, while the buffer zones of 2,000~3,000 m were given a grading of 5 (Fig. 3h).

2.5.9 Railway

In this study, buffer zones of less than 500 m on both sides of a railway were graded 0. Distances greater than 500 m were graded 10 (Fig. 3i).

2.5.10 Urban Centers

To determine suitable locations for landfill from borders of urban areas, buffer zones of less than 5 km were given a grading of 0. This figure was adopted due to many factors such as land value, health and safety laws (which often prevent siting of a landfill within the boundaries of an urban area) noise, decreases in property value [44], odor, aesthetics [45] and allowances for ensuring the potential to expand the urban area in the future [27].

Buffer zones between 5~10 km were given the highest score which was 10. Buffer zones of 10~15 km and more than 15 km were given a score of 7 and 4, respectively (Fig. 4a).

2.5.11 Villages

For rural areas, buffer zones less than 1,000 m were given a grading value of 0, while those with buffer zones greater than 1,000 m were given a score of 10 (Fig. 4b).

2.5.12 Archaeological Sites

For archaeological and religious sites, buffer zone of less than 1 km around these areas was restricted and, thus, scored 0. Buffer zones more than 3 km, and buffer zones of 1~3 km around these areas were scored 10 and 5, respectively (Fig. 4c).

2.5.13 Gas Pipelines

The necessary buffer zone from gas pipelines on both sides to a landfill site was 300 m, and it was given a grading value of 0 according to the determinations of the Iraqi Ministry of Oil/Oil Pipelines Company in 1989 [46]. Buffer zones more than 300 m were given a score value of 10 (Fig. 4d).

2.5.14 Oil Pipelines

Buffer zones less than 75 m on both sides of oil pipelines to a landfill site were giving a score of 0. Buffer zones more than 75 m are considered a safe distance according to the determinations of the Iraqi Ministry of Oil/Oil Pipelines Company in 1989 [46], and were given a grading value of 10 (Fig. 4e).

2.5.15 Power Lines

In this study, buffer zones from a landfill site to

power lines on both sides should be more than 30 m, and these were given a score of 10. The reasons for choosing this value were to avoid the high level of voltage power that results from these lines, and to provide electricity for the infrastructure in a landfill site [33, 39]. Distances less than 30 m was given a grading of 0 (Fig. 4f).

2.6 Evaluation Criteria's Weights Using AHP Method

The AHP developed in 1980 by Saaty [12], is a powerful and comprehensive decision-making methodology. It is one of the most common methods applied to multi-criteria in making decisions. This process allows a decision maker to make the right decision by using empirical data alongside the subjective judgments of the decision maker [13, 47].

In the AHP method, the hierarchy is deconstructed into a series of pair-wise comparisons to determine the relative weighted importance of each criterion in terms of the other criteria. A 9-point numerical scale is used in a typical analytic hierarchy in order to indicate how many times more important or how dominant one criterion is over another criterion with respect to the criteria. This scale was presented by Saaty [12] in 1980 and further developed in 2008 [48] (Table 3).

In this study, the typical structure of the decision-making problem is formed and consists of numbers, which were represented by symbol m , while alternatives were given numbers represented by symbol n . The values of a_{ij} ($i = 1, 2, 3, \dots, m$) and ($j = 1, 2, 3, \dots, n$) are used to signify the performance values in terms of the i -th and j -th in a matrix. The upper triangular of the matrix is filled with the values of comparison criteria above the diagonal of the matrix. In order to fill the lower triangular of the matrix, the reciprocal values of the upper diagonal are used. This is done by using the Eq. (1):

$$a_{ji} = 1/a_{ij} \quad (1)$$

where, a_{ij} is the element of row i and column j of the matrix [17, 49, 50]. The typical comparison matrix for any problem and the relative importance of the criteria

Fig. 4 Suitability index maps of: (a) urban centers; (b) villages; (c) archaeological sites; (d) gas pipelines; (e) oil pipelines; (f) power lines.

Table 3 The fundamental scale of absolute numbers [48].

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgment slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgment strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favored very strong over another; Its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation

can be represented in a decision matrix as follows:

$$\begin{pmatrix} a_{11} & a_{12} & \dots & a_{1n} & W_1 \\ a_{21} & a_{22} & \dots & a_{2n} & W_2 \\ \dots & \dots & \dots & \dots & \dots \\ a_{m1} & a_{m2} & \dots & a_{mn} & W_n \end{pmatrix}$$

The eigenvectors were calculated for each row using geometric principles in Eq. (2):

$$Eg_i = \sqrt[n]{a_{i1} \times a_{i2} \times a_{i3} \times \dots \times a_{in}} \quad (2)$$

where, Eg_i = eigenvalue for the row i ; n = number of

elements in row i .

The priority vector was determined by normalizing the eigenvalues to 1 (divided by their sum) as follows:

$$Pr_i = Eg_i / (\sum_{k=1}^n Eg_k) \quad (3)$$

The lambda max ($\lambda_{\max}$) was obtained from the summation of products between each element of the priority vector and the sum of columns of the reciprocal matrix as shown in the following Eq. (4):

$$\lambda_{\max} = \sum_{j=1}^n [W_j \times \sum_{i=1}^m a_{ij}] \quad (4)$$

where, a_{ij} = the sum of criteria in each column in the matrix; W_i = the value of weight for each criterion corresponding to the priority vector in the matrix of decision, where the values $i = 1, 2, \dots, m$, and $j = 1, 2, \dots, n$. So, the lambda max ($\lambda_{\max}$) in this study is equal to 15.6.

The CI (consistency index) was estimated using the following Eq. (5):

$$CI = (\lambda_{\max} - n) / (n - 1) \quad (5)$$

where, CI represents the equivalent to the mean deviation of each comparison element and the standard deviation of the evaluation error from the true ones [51], and n is size or order of the matrix. In this study, $CI = 0.04$.

The CR (consistency ratio) was obtained based on

Saaty [12], by dividing the value of CI by the RI (random index) value ($RI = 15.9$) for $n = 15$ (Table 4), where Table 4 displays mean RI for matrices with different sizes [34, 52]:

$$CR = CI / RI \quad (6)$$

If the value of CR is smaller than 10%, the ratio indicates a reasonable consistency level in the pair-wise comparison. In this study, $CR = 0.027 < 0.1$ and $RI_{15} = 1.59$. For any matrix, the judgments are completely consistent if a CR is equal to 0 [53]. Fig. 5 shows the pair-wise comparison matrix and relative importance weights for the selection site for landfill in the study area.

In order to find the suitability index value of the potential areas, the method of WLC (weighted linear combination) was used based on the following Eq. (7):

$$A_i = \sum_{j=1}^n W_j \times C_{ij} \quad (7)$$

where, A_i is the suitability index for area i , W_j is the relative importance weight of criterion, C_{ij} is the grading value of area i under criterion j and n is the total number of criteria [7, 30].

This Eq. (7) was applied on all criteria using the extension tool “map algebra” in GIS. The procedures

Table 4 Random inconsistency indices for different values of n [36, 54].

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	Eigen vector	Normalized weights
A	1	2	3	2	4	5	5	4	8	8	7	6	5	6	9	4.33	0.2004
B	0.50	1	2	1	3	4	4	3	7	7	6	5	4	5	8	3.18	0.1471
C	0.33	0.50	1	0.5	2	3	3	2	6	6	5	4	3	4	7	2.24	0.1038
D	0.50	1.00	2.00	1	3	4	4	3	7	7	6	5	4	5	8	3.18	0.1471
E	0.25	0.33	0.50	0.33	1	2	2	1	5	5	4	3	2	3	6	1.53	0.0709
F	0.20	0.25	0.33	0.25	0.50	1	1	0.5	4	4	3	2	1	2	5	1.00	0.0463
G	0.20	0.25	0.33	0.25	0.50	1.00	1	0.5	4	4	3	2	1	2	5	1.00	0.0463
H	0.25	0.33	0.50	0.33	1.00	2.00	2.00	1	5	5	4	3	2	3	6	1.53	0.0709
I	0.13	0.14	0.17	0.14	0.20	0.25	0.25	0.20	1	1	0.5	0.34	0.25	0.34	2	0.32	0.0146
J	0.13	0.14	0.17	0.14	0.20	0.25	0.25	0.20	1.00	1	0.5	0.34	0.25	0.34	2	0.32	0.0146
K	0.14	0.17	0.20	0.17	0.25	0.33	0.33	0.25	2.00	2.00	1	0.5	0.34	0.5	3	0.45	0.0207
L	0.17	0.20	0.25	0.20	0.33	0.50	0.50	0.33	2.94	2.94	2.00	1	0.5	1	4	0.65	0.0302
M	0.20	0.25	0.33	0.25	0.50	1.00	1.00	0.50	4.00	4.00	2.94	2.00	1	2	5	1.00	0.0462
N	0.17	0.20	0.25	0.20	0.33	0.50	0.50	0.50	2.94	2.94	2.00	1.00	0.50	1	4	0.65	0.0302
O	0.11	0.13	0.14	0.13	0.17	0.20	0.20	0.33	0.50	0.50	0.33	0.25	0.20	0.25	1	0.23	0.0107

Fig. 5 Pair-wise comparisons matrix for selecting a suitable landfill site, eigenvector and significance weights.

Note: A: groundwater depth; B: urban centers; C: villages; D: rivers; E: elevation; F: slope; G: roads; H: soils types; I: gas pipelines; J: oil pipelines; K: power lines; L: land use; M: agricultural land use; N: archaeological sites; O: railways.

for estimating the suitability index were done through the summation of the products of multiplying the grading values of the sub-criteria for each criterion (based on the opinion of experts in this field) by the corresponding relative importance weight (which was calculated by the AHP method). The final value of suitability index was obtained according to the grading scale of 1~5, which was ranging from the lowest value of an unsuitable site to the highest value of the most suitable for a site [30].

3. Results and Discussion

After determining the weights for each criterion using the AHP method, suitable weightings for the sub-criteria of each criterion based on the opinion of experts in this field were assigned. The WLC method was used to determine the final output map of the suitability index for a landfill siting in Al-Qasim Qadhaa. This map was divided into five categories:

- unsuitable;
- moderately suitable;
- suitable;
- most suitable;
- excluded areas.

The category of “excluded areas” included urban centers, villages, rivers, archaeological sites, a university location and industrial areas. These areas were given a value of 0. The area for each category and its proportion of the total study area were as follows:

- The “unsuitable” class is 50.76 km² (8.74%);
- The “moderately suitable” class is 234.46 km² (40.38%);
- The “suitable” class is 206.47 km² (35.56%);
- The “most suitable” class is 70.92 km² (12.22 %);
- The “excluded areas” is 17.97 km² (3.1%) (Fig. 6a).

The solid waste quantity expected in 2030 in Al-Qasim Qadhaa is 71,947 t. The cumulative quantity of solid waste expected from 2020 to 2030 is 632,990 t based on an expected population in 2030 in this Qadhaa of 304,621 inhabitants, according to calculations made by Chabuk et al. [54]. The density of waste in waste disposal sites is 450 kg/m³ in the Babylon Governorate and, consequently, in Al-Qasim Qadhaa [55]. By dividing the solid waste quantity over the density of waste, the expected volume of waste and the predictable volume of cumulative waste in 2030 are 159,882 m³ and 1,406,644 m³, respectively. An average groundwater depth of 2 m in the candidate

Fig. 6 Final maps of suitability index for landfill siting: (a) final model map of a suitable landfill; (b) the candidate sites for landfill in Al-Qasim Qadhaa.

sites for landfill in the study area was adopted because the groundwater depth from a ground surface in Al-Qasim Qadhaa is shallow. Therefore, the required area of a candidate site to accommodate the cumulative quantity of solid waste generated from 2020 to 2030 is 0.702 km².

Two candidate sites were selected for landfill among the many sites located within the category of the “most suitable” index. These sites were each assigned a number (1 and 2). The area of Site No. 1 is 2.766 km², while the area of Site No. 2 is 2.055 km². These candidate sites are suitable for landfill in Al-Qasim Qadhaa. Fig. 6b shows that Site No.1 is situated at latitude 32°11'43" N, and longitude 44°32'26" E, while Site No. 2 is situated at latitude 32°14'38" N, and longitude 44°37'10" E.

4. Conclusions

This study aimed to select suitable sites for landfill in Al-Qasim Qadhaa using the best methodology and also by taking into account the scientific and environmental criteria which are followed in advanced countries. In order to determine the most suitable site for solid waste landfill in Al-Qasim Qadhaa, 15 layers were incorporated in the process of analysis using GIS, which is considered a powerful tool for assisting in the selection of a site for landfill due to its ability to deal with a large volume of data from different sources. Here, these layers were groundwater depth, rivers, soil types, agriculture land, land use, elevation, slope, gas pipelines, oil pipelines, power lines, roads, railways, urban centers, villages and archaeological sites. An AHP was used to derive the weightings for multi-criteria using a pair-wise comparison to construct a comparison matrix. Then, a WLC method was used to produce a suitability index for the final output map for the study area.

Finally, in the category of “most suitable” on the final map, two candidate sites were identified for landfill among several sites. These sites were checked on the satellite images (2011) of the Babylon

Governorate to make sure that these sites were suitable for landfill. Generally, these sites satisfy the minimum requirements of the landfill sites. The area of Sites No. 1 and No. 2 are 2.766 and 2.055 km², respectively. The required area in the present study that can well accommodate such waste was 0.702 km². This area was estimated based on expected solid waste for the period 2020 to 2030 as 632,990 t and was also based on the current waste generation rate and population growth rate in this Qadhaa, which were 0.58 kg per capita day, and 2.99%, respectively.

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